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Water and economic growth in OPEC country

(Approach in the government management of resources operational)

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Abstract

The influence of water utilization on economic growth is depicted through a growth model that includes this congestible public good as a productive input for private producers. Growth is negatively affected by the government's appropriation of output to supply water but positively influenced by the contribution of increased water use to capital productivity, leading to an inverted-U relationship between economic growth and the rate of water utilization. Cross-country estimations confirm this relationship and suggest that for most economies current rates of freshwater utilization are not yet constraining growths. However, for a handful of countries, moderate or extreme water scarcity may affect economic growth adversely

Keywords: Congestible public goods, cross-country regressions, economic growth, freshwater;

1. Introduction

As global water withdrawals increase, policy analysis increasingly requires refined understanding of the causes, correlates, and implications of such trends. Predictions of coming wars over water are commonly found in statements by political officials, research studies by academics, popular journalistic sources, and reports by environmental and development oriented non-governmental organizations. A search on any popular search engine of the term "water wars" will turn up thousands of such references.
Modelling the relationship between water use and economic growth in an economy requires first determining what type of economic good is water. Although in some economies there is increasing reliance on the involvement of the private sector in providing some water services, with little loss of generality, one can and view the aggregate supply of water utilized by a country as a government-provided public good subject to congestion. Following the approach Of Barro (1990) and Barro and Sala-I-Martin (1995), modelling the influence of water utilization on economic growth allows the development of a growth model that includes publicly provided goods that are subject to congestion as a productive input for private producers in an economy.

If water has the characteristic of a public good subject to congestion, then there are essentially two ways in which water scarcity may affect economic growth. First, as water becomes increasingly scarce in the economy, the government must exploit less accessible sources of freshwater through appropriating and purchasing a greater share of aggregate economic output, in terms of dams, pumping stations, supply infrastructure, etc. Second, it is also possible that water utilization in an economy may be restricted by the absolute availability of water. Thus the

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influence of water use on growth may be different for a water-constrained economy. As a consequence, in our model we distinguish between the case in which water is not a binding constraint in the economy and the case in which it is binding.

In the interior solution with no absolute water scarcity constraint, our model suggests that there is a concave, or inverted-U, relationship between growth and the rate of water utilization. The socially efficient rate of water utilization also ensures that the per capita growth rate is at its maximum. For the water-constrained economy, if too high a proportion of output is allocated to Provide water, then the negative effects of allocating more output to obtain the extra water will exceed any gains in productivity. The result is that the economy will decline.

The theory results of this paper provide strong support for the hypothesized inverted-U relationship between economic growth and the rate of water utilization across countries. Estimations of this relationship also suggest that current rates of freshwater utilization in the vast majority of countries are not yet constraining economic growth. To the contrary, there is probably scope for many countries to increase freshwater use provided it is done efficiently - and still achieve higher growth rates. However, our empirical analysis also suggests that, for a handful of countries, it is difficult to reject the hypothesis that the presence of moderate or extreme water scarcity adversely affects economic growth. Nevertheless, even for water-scarce countries, there appears to be little evidence that there are severe diminishing returns to allocating more output to provide water, thus resulting in falling income per capita. Thus the results of this paper suggest caution over the claims of some hydrological-based studies that by 2020 at least 7 countries are likely to face "absolute" water scarcity, and an additional 5 countries may face "economic" water.

2. Defining Water-based Conflict and Water Scarcity

Water is an essential resource for life and good health. A lack of water to meet daily needs is a reality today for one in three people around the world. Globally, the problem is getting worse as cities and populations grow, and the needs for water increase in agriculture, industry and households. This fact file highlights the health consequences of water scarcity, its impact on daily life and how it could impede international development. It urges everyone to be part of efforts to conserve and protect the resource.

In popular usage, "scarcity" is a situation where there is insufficient water to satisfy normal requirements. However, this common-sense definition is of little use to policy-makers and planners. There are degrees of scarcity: absolute, life-threatening, seasonal, temporary, cyclical, etc. Populations with normally high levels of consumption may experience temporary scarcity more keenly than other societies accustomed to using much less water. Scarcity often arises because of socio-economic trends having little to do with basic needs Water scarcity is a more relative concept describing the relationship between demand for water and its availability. The demands may vary considerably between different countries and different regions within a given country depending on the sectoral usage of water. A country with a high industrial demand or which depends on large scale irrigation will therefore be more likely to experience times of scarcity than a country with similar climatic conditions without such demands. Countries such as Rwanda, for example, would be classified by most standards as suffering water shortage but, because of low industrial and irrigation utilization would not be classified as water scarce.

3. A Model of Water Use and Economic Growth

Hydrologists also distinguish two concepts of water use: water withdrawal and water Consumption. Withdrawal refers to water removed or extracted from a freshwater source and used for human purposes. However, some of this water may be returned to the original source, albeit with changes in the quality and quantity of the water. In contrast, consumptive use is water withdrawn from a source and actually consumed or lost to seepage, contamination, or a "sink" where it cannot economically be reused. Thus water consumption is the proportion of water withdrawal that is "irretrievably lost" after human use.

In this study, we will use average annual water withdrawals (km3/year) as our measure of Freshwater utilization. There are two reasons for this. First, the available data across a broad range of countries is much more reliable and accurate for water withdrawals than consumption.

Second, hydrologists' measures of water stress and scarcity are usually couched either in terms of water availability per person (cubic meters per person per year) or in terms of relative water demand.

Let w be the annual per capita renewable freshwater resources of a country (in cubic meters per person per year), and let r be total per capita freshwater utilization by that country (in cubic meters per person per year). In essence, w represents the hydrologists' concept of the total annual water supplies available to an economy on a per capita basis, whereas r is the actual supply provided and used, i.e. the water withdrawal.

As suggested by Barro (1990) and Barro and Sala-I-Martin (1995), the actual supply of water withdrawn and utilized by a country, for domestic, agricultural and industrial purposes, has the characteristics of a government-provided public good subject to congestion. That is, modelling the influence of per capita water withdrawal, r, on the growth of the economy can be depicted through a growth model that includes this congestible public good as a productive input for private producers.

The contribution of water utilization or withdrawal, r, to the per capita output of the *ith* producer, *yi*, can therefore be represented as

$$Y_i = AK_iF\left(\frac{r}{y}\right), \quad f' > 0\,, f'' < 0 \tag{1}$$

Following Rebelo (1991), part of private production depends on constant returns to the per capital stock available to the producer, k_i, which is broadly defined to include both physical and human capital components, and $A > 0$ is a parameter reflecting the level of technology. In addition, production increases with respect to the amount of water utilization, which is supplied through public services. However, because of congestion, the flow of water available to the *ith* producer is necessarily limited by the use of water by all producers in the economy. Denoting aggregate per capita output across all N producers in the economy as $y = Ny_i$, it follows that water utilization, r, has to increase relative to y in order to expand the water available to the *ith* producer. In contrast, an increase in per capita output relative to total water utilization in the economy lowers the water available to each producer, and therefore reduces y_i in (1).

Not only may the aggregate water supplies in an economy have the characteristic of a public good subject to congestion but also the provision of these supplies may be affected by the physical availability of these supplies, or water scarcity. There are two ways in which this may occur.

First, it can be generally assumed that the government provides water for use in the economy by appropriating a share of aggregate private output. For example, in modelling the supply of general public goods, Barro (1990) has argued that one can think of government simply purchasing a flow of output from the private sector, the services of which the government in turn makes available to the economy as a whole. In order to provide the water utilized by the economy, r, one can also envision the government purchasing or appropriating a share, z, of aggregate economic output that is specifically devoted to water supply. This suggests that$r = zy$. However, as per capita freshwater utilization in the economy, r, rises relative to the available annual per capita annual renewable freshwater resources, w, one would also expect that more aggregate output must be allocated for water supply.

As water becomes increasingly scarce, i.e. water utilization rises relative to available freshwater resources; the government must exploit less accessible sources of freshwater. To do this, requires appropriating and purchasing a greater share of aggregate economic output, in terms of dams, pumping stations, supply infrastructure, etc. Denoting $\rho = r/w$ as the rate of water utilization relative to total freshwater availability, it therefore follows that

$$r = z(\rho)y\ , z' > 0\,, z'' > 0, z(0) = 0, z'(0) = 0, z(1) = \alpha, z'(1) = \beta < \infty \tag{2}$$

Where $\beta > 0$, $0 < \alpha < 1$, and $z(\rho) < 1$ is the proportion of aggregate economic output appropriated by the government for providing water, which is assumed to be an increasing function of the rate of water utilization by the economy relative to its freshwater resources, ρ. In addition, as aggregate output, y, rises in the economy, so does water utilization, r. Finally, as water becomes increasingly scarce, i.e$\rho \to 1$, the proportion of output appropriated by the government to Supply water is bounded above by α, and the rate of appropriation by β.

Water scarcity also influences water utilization in an economy by limiting the total amount of water available for withdrawal. That is, even if all freshwater resources are used (i.e. $\rho = 1$), water withdrawals are finite. Thus total per capita freshwater availability imposes the following constraint on the economy

$$r = z(\rho)y \le w \tag{3}$$

$$with\ r = z(\rho) < w\ \ if\ \ 0 \le \rho < 1\ \ and\ r = z(\rho) = w\ \ if\ \ \rho = 1$$

Making the standard assumption that the supply of labor and population are the same, and that population grows at the constant rate n, per capita output in the economy is allocated as

$$y = c + r + \dot{k} + (\omega + n)k\,,\; k(0) = k_0 \qquad (4)$$

Where c is per capita consumption, $k\_$ is the change in the per capita capital stock over time and ω is the rate of capital depreciation. Finally, all consumers in the economy are assumed to share identical preferences over an infinite time horizon, given by

$$w = \int_0^\infty e^{-\delta t}\left[\frac{c^{1-\theta}-1}{1-\theta}\right]dt \quad , \; \delta = \upsilon - n \geq 0 \qquad (5)$$

Where υ is the rate of time preference. Maximization of W with respect to choice of c and ρ, subject to (1) to (4), yields the following Lagrangian expression

$$L = \frac{c^{1-\theta}-1}{1-\theta} + \lambda\big[(1 - z(\rho))Akf(z(\rho)) - c - (\omega + n)k\big] + \mu[w - z(\rho)Akf(z(\rho))] \qquad (6)$$

The resulting first-order conditions are

$$c^{-\theta} = \lambda \qquad (7)$$

$$\lambda\big[(1 - z(\rho))Akf'z'\big] - \lambda Akf(z(\rho))z' = \mu\big[Akf(z(\rho))z' + z(\rho)Akf'z'\big] \qquad (8)$$

$$\mu(t) \geq 0\,, w - z(\rho)Akf(z(\rho)) \geq 0, \mu\big[w - z(\rho)Akf(z(\rho))\big] = 0$$

$$\dot{\lambda} = \delta\lambda - \lambda\big[1 - z(\rho)Af(z(\rho)) - (\omega + n)\big] + \mu z(\rho)Af(z(\rho)) \qquad (9)$$

$$\lim_{t\to\infty}\{e^{-\delta t}\lambda(t)k(t) = 0\} \qquad (10)$$

Equation (8) determines the optimal allocation of the rate of water utilization of the economy, including the complementary slackness condition imposed by the water scarcity constraint. The Lagrangean multiplier μ can be interpreted as the scarcity value of freshwater supplies to the economy. Equation (9) indicates the change over time in the value of the capital stock of the economy. Finally, equation (10) is the transversality condition for this infinite time horizon problem.

Differentiating (7) with respect to time and substituting into (9) yields

$$g = \frac{\dot{c}}{c} = \frac{1}{\theta}\Big[(1 - z(\rho)Af(z(\rho)) - (\omega + n + \delta) - \mu\frac{z(\rho)Af(z(\rho))}{c^{-\theta}}\Big] \qquad (11)$$

The above equation indicates that growth in per capita consumption is negatively affected by the government's appropriation of output to supply water, 1 – z(ρ), positively influenced by the contribution of water use to the net marginal productivity of capital, $Af(z(\rho))$ □□(ω□□n □□δ) , and adversely impacted by conditions of water scarcity, μ□$z(\rho)Af(z(\rho))$ /$c^{-\theta}$ Further interpretation of the influence of water use on growth in the economy requires examining the conditions under which the water scarcity constraint (3) is binding or not.

4. Water Scarcity Is Not Binding in the Economy

If the water scarcity constraint (3) is not binding, then the complementary slackness condition requires that $w > r$ and μ(t) = 0 for all t. For this interior solution, equation (11) reduces to

$$g = \frac{1}{\theta}\Big[\big(1 - z(\rho)\big)Af(\rho)\Big) - (\omega + n + \delta)\Big] \qquad (12)$$

Although water scarcity no longer affects the growth in per capita consumption, g is still influenced by water utilization in the economy. Growth is negatively affected by the government's appropriation of output to supply water, 1 – z(ρ), and positively influenced by the contribution of water use to the net marginal productivity of capital, $Af(z(\rho))$ −□(ω□□n □ δ) .

Moreover, it can be easily demonstrated that in this economy per capita consumption, capital and output all grow at the same rate g, and there are no transitional dynamics to this steady-state growth path. In the initial period, the socially efficient level of water use, ρ*, that satisfies (8) for μ(0) = 0 is chosen, along with the initial values for per capita consumption and output. After the initial period, $k(t)$, $c(t)$ and $y(t)$ then grow at the constant rate determined by (12). It is also straightforward to demonstrate that the socially efficient rate of water utilization, ρ*, maximizes growth in the economy. Differentiating (12) with respect to ρ we get

$$\frac{\partial g}{\partial p} \begin{matrix} > \\ = \\ < \end{matrix} \quad if \quad f(z(\rho)) \begin{matrix} > \\ = \\ < \end{matrix} (1 - z(\rho))f'(z(\rho)) \qquad (13)$$

Thus the socially efficient rate of water utilization that satisfies (8) also ensures that the per capita growth rate is at its maximum, g^*. Moreover, as $z(\rho)$ is strictly convex, it follows that the slope of (12) with respect to the rate of water utilization is positive for $\rho < \rho^*$, and conversely, is negative for $\rho > \rho^*$. Consequently, as depicted in Figure 1, the relationship between growth and the rate of water utilization is concave.

5. The Water-Constrained Economy

We now turn to the case where the water scarcity constraint (3) is binding in the economy, and thus the complementary slackness condition requires that $w = r$ and $\mu(t) > 0$ for all t. Equation (2) also implies that $z(1) = \frac{r}{y} = \frac{w}{y} = \alpha \, , z'(1) = \beta < \infty$

That is, the proportion of aggregate economic output appropriated by the government for providing water is now determined by the ratio of the potential water supplies to aggregate output, which is bounded by the maximum rate of appropriation, α.

For the water-constrained economy, growth in per capita consumption is now governed by a modified version of equation (11), with the rate of output appropriated by the government to supply water set at the maximum rate, α

$$g_s = \frac{\dot{c}}{c} = \frac{1}{\theta}\left[(1-\alpha)Af(\alpha) - (\omega + n + \delta) - \mu\frac{\alpha A f(\alpha)}{\lambda}\right] \tag{14}$$

Growth in the water-constrained economy, g_s, is positively influenced by the net marginal productivity of capital, $Af(\alpha)$ □□(ω□□n □□δ) , including the contribution of water use to this productivity, but adversely affected by the government's appropriation of output to supply water, 1 – α, and by the conditions imposed by water scarcity, $\mu\alpha Af(\alpha)/\lambda$□. For the water-constrained economy, condition (8)

$$\mu = \lambda\left[\frac{f'(\alpha)}{f(\alpha)+\alpha f'(\alpha)} - 1\right] > 0$$

Using the latter expression, (14) can be simplified further to

$$g_s = \frac{1}{\theta}\left[Af(\alpha) - (\omega + n + \delta) - \alpha A f(\alpha)\left(\frac{f'(\alpha)}{f(\alpha)+\alpha f'(\alpha)}\right)\right] \tag{15}$$

In the initial period, the government chooses the maximum rate of appropriating economic output in order to supply freshwater, $\alpha y = r = w$, along with the initial values for per capita consumption and output. Although in a water-constrained economy it is always optimal for the government to appropriate output at the maximum rate, α, to supply freshwater, this does not necessarily mean that economic growth will occur. From (15),

$$g_s \gtreqless 0 \quad if \quad Af(\alpha) - (\omega + n + \delta) \gtreqless \alpha A f(\alpha)\frac{f'(\alpha)}{f(\alpha)+\alpha f'(\alpha)} \tag{16}$$

That is, growth in the water-constrained economy will occur only if the net marginal productivity of capital exceeds the negative effects on the economy of water scarcity.

6. Cross-Country Empirical Analysis of Water and Growth in OPEC countries

The above theoretical analysis of the relationship between growth and water utilization suggests the possibility of a concave, or "inverted-U", relationship (see Figure 1). That is, as the rate of water utilization, ρ, in an economy increases, economic growth, g, first increases, then stabilizes and eventually falls. This is the normal case that we would expect for an economy in which water availability is not an absolute binding constraint.

The ratio of freshwater withdrawals, r, relative to supplies, w, can therefore serve as our cross-country measure of $\rho = r/w$. In addition, because different sources are used to provide these estimates, the year in which r and w is estimated varies greatly from country to country. Given these limitations, it is therefore possible to estimate a cross-country relationship between economic growth and ρ through cross-sectional as opposed to pooled cross-sectional and time series (i.e. panel) analysis. In empirically examining the hypothesized the inverted-U relationship between g and ρ, one must also be aware of several issues raised in the general literature on estimating cross country growth relationships. First, most researchers generally have opted for the five or ten-year averages of annual growth rates in order to avoid any business cycle effects.

The following basic empirical specification can be used to test the hypothesis that there is an inverted-U relationship between growth and the rate of water utilization across countries:

$$g_{t,t+5} = b_0 + b_1\rho_t + b_2\rho_t^2 + \mu \quad (17)$$

Where the dependent variable is the five-year average growth rate for each country, beginning at the year of estimate, *t*. Note that $b_1 > 0$ and $b_2 < 0$ implies that the inverted-U hypothesis holds.

The implication for our model is that, if the hypothesized U-shaped relationship between growth and the rate of water utilization is robust, then this relationship should also hold if the normal set of "fixed" variables, $\boldsymbol{x}$, that account for growth across countries is also included. We therefore also estimate the following basic growth regression:

$$g_{t,t+5} = b_0 + b_1\rho_t + b_2\rho_t^2 + b_x x + \mu \quad (18)$$

Following Sala-I-Martin (1999) and Temple (1999), we choose the "fixed" variables, **x**, to be the initial level of income per capita in year *t*, the primary-school enrolment rate in year *t* and the secondary-school enrolment rate in year *t* Finally, the empirical literature on growth has also identified consistently a number of other variables that appear to be significantly correlated with growth across countries. This suggests that, extending our growth model further to include these additional explanatory variables, $\boldsymbol{y}$, should not affect the hypothesized U-shaped relationship between growth and the rate of water utilization, if that relationship is robust. Our full growth model for empirical estimation is:

$$g_{t,t+5} = b_0 + b_1\rho_t + b_2\rho_t^2 + b_x x + b_y y + \mu \quad (19)$$

Where $\boldsymbol{y}$ includes, for each country in the sample, an index of political stability/lack of political Violence, an index of the control of corruption, the annual population growth rate in year *t*, total trade as a percentage of real GDP in year *t* and a dummy variable indicating whether the country is classified as a developing economy. In fact, as our theoretical model indicates, for an economy in which water scarcity is binding, i.e $w = r$ and therefore $\rho = 1$, the resulting scarcity constraint will have very different implications for the economy's growth path. Economic growth is now determined by the ratio of the potential water supplies to aggregate output, which is equal to the maximum rate of government appropriation, i.e. $w/y = \alpha$.

Empirically verifying condition (16) and the growth path of the water-constrained economy is very difficult for our data set. First, only ten out of the 12 countries in our sample display rates of water utilization of $\rho > 1$. This is too small a sub-sample for conducting a separate regression. Second, as noted above, our data set contains only a single-year estimate of the rate of water utilization for each country. Some countries that have rates of water utilization of $\rho > 1$ in a single year may not necessarily experience chronic water scarcity over a longer period of time, as implied by our model of the water-constrained economy.

Nevertheless, provided that we can use an appropriate indicator of long-run water scarcity across countries, it may be possible to test an alternative hypothesis, namely that growth rates are likely to be adversely affected in economies facing chronic water scarcity.

7. Conclusion

In the case of the economy in which there is no absolute water scarcity constraint, our model suggests that there is a concave, or inverted-U, relationship between growth and the rate of water utilization (see Figure 1). Moreover, the socially efficient rate of water utilization also ensures that the per capita growth rate is at its maximum, g^*. In contrast, over or under-use of water is likely to result in less overall growth in the economy. For the water-constrained economy, the relationship between growth and the rate of water utilization is likely to be more complex. Although it is always optimal for the government to appropriate output at the maximum rate, α, to supply freshwater, this does not necessarily mean that economic growth will occur (see equation (16)). Growth requires, firstly, that the net marginal productivity of capital exceeds the negative effects on the economy of water scarcity, and secondly, that there are sufficient freshwater resources, *w*, available to appropriate.

The model analysis of this paper provides strong support for the hypothesized inverted-U relationship between economic growth and the rate of water utilization across countries. Our estimations of this relationship also suggest that current rates of freshwater utilization in the vast majority of countries are not yet constraining economic growth. To the contrary, most countries may be able to increase growth by utilizing more of their freshwater resources – provided they do so efficiently - although there are obvious limits on how much additional growth can be generated in this way. Countries that are "water stressed", i.e. have limited freshwater supplies relative to current and future populations, may find it especially difficult to generate additional growth through more water use. Our empirical analysis suggests that we cannot reject the hypothesis that the presence of moderate or extreme water scarcity adversely affects economic growth.

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Table 1. Cross-Country Regression of Water Use and Growth

Dependent variable: Five-year average annual growth of per capita income

Variables	**Basic growth model**[†]		**Full growth model**[‡]		
Constant	-1.657 (3.546)[§]		10.234(3.243)		
ρ	1.846 (6.353)		2.324 (2.634)		
ρ^2		-0.342 (-8.945)		-.0348 (2.793)	
Log per capita income in year *t*	-0.035 (-0.351)		-1.243 (-3.512)		
Primary school enrollment in year *t*	0.032 (2.123)		0.021 (1.451)		
Secondary school enrollment in year *t*	-0.0043 (-0.431)		0.003 (-0.632)		
Population growth in year *t*			-4.254 (-1.763)		
Trade openness in year *t*			-0.004 (-0.423)		
Political stability indicator			1.143 (2.526)		
Dummy for OPEC countries			2.856 (3.512)		
Inverted-U relationship	**Yes**	**Yes**	**Yes**		
(Estimate of ρ*)	(3.325)	(2.955)	(3.573)		
Elasticity of ρ	**0.302**	**0.298**	**0.311**		
(Sample mean of ρ)		(0.328)		(0.322)	(0.382)
Wald statistic	99.500	88.110	104.799		
Breusch-Pagan LM statistic	1.743	2.936	32.831		

[†] - Ordinary least squares employing standard errors based on White's heteroskedasticity consistent variance-covariance matrix.
[‡] - Maximum likelihood estimation after correcting the variance-covariance matrix for multiplicative heteroskedasticity. t-statistics are in parentheses.
[§] - Significant at 1% level. *Significant at 5% level. †Significant at 10% level.